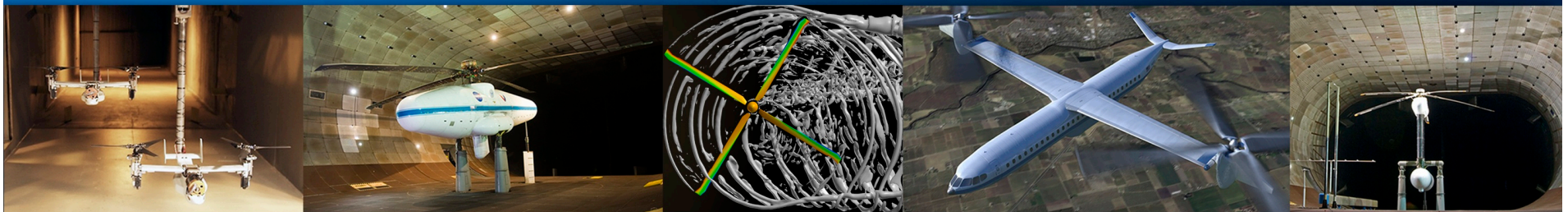




Improved Coupling for UH-60 Performance Prediction

Ethan Romander

UH-60 Airloads Workshop – March 8, 2012



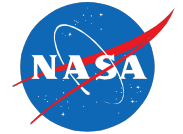
Aeromechanics Branch - NASA Ames Research Center

Overview



- Part 1 – Force Conservation in Coupled Simulations
 - Review of presentation from Aug. 2011
 - New results with improved azimuthal resolution
- Part 2 – Preliminary Comparisons of Measured/Predicted Blade Motion
 - Introduction to measurement technique
 - Rigid Body Motion (RBM) comparisons
 - Elastic deformation comparisons

Software Toolkit



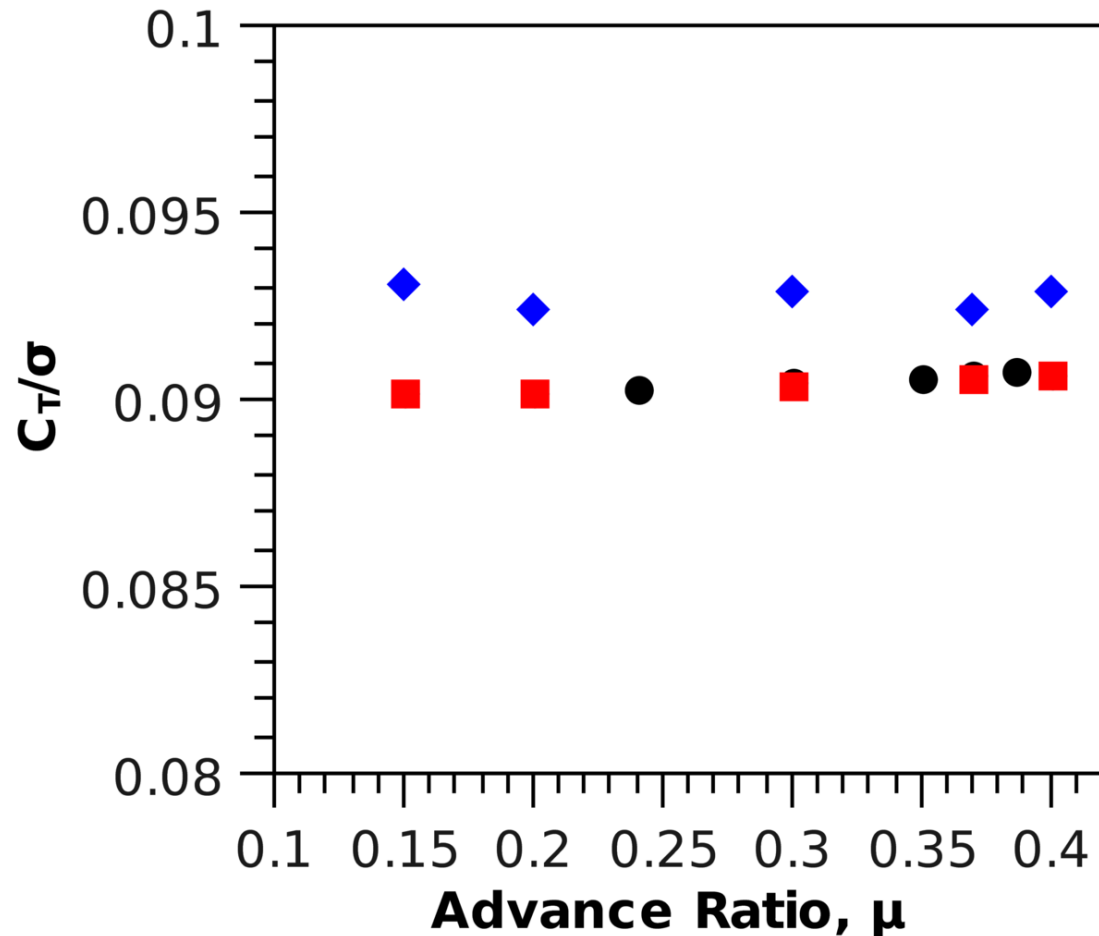
- CFD: OVERFLOW2 v2.2b
 - 4th order central differencing in space; 2nd order dual timestepping
 - Spalart-Almaras 1-eq. turbulence model with rotational corrections (inviscid off-body)
 - Blade surfaces modeled as fully-turbulent, viscous, adiabatic walls
- Comprehensive: CAMRADII v4.6
 - CSD: non-linear finite elements
 - Control system, trim
- Loose delta-coupling technique
 - OVERFLOW2→CAMRADII = sectional airload deltas (normal force, chord force, and pitching moment)
 - CAMRADII→OVERFLOW2 = blade motions (elastic deformations plus rigid motions)

Speed Sweep Overview



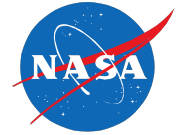
- Run 52 from 40x80 Airloads test
- $\mu=0.15-0.4$, $M_{\text{tip}}=0.65$, $C_L/\sigma=0.09$
- Predictions matched corrected α_s and trimmed to match tunnel loads— C_T , $C_{M,R}$, $C_{M,P}$ —at each speed.
- All performance indices are integrated from CFD solution.

Comprehensive code predicts somewhat different values.



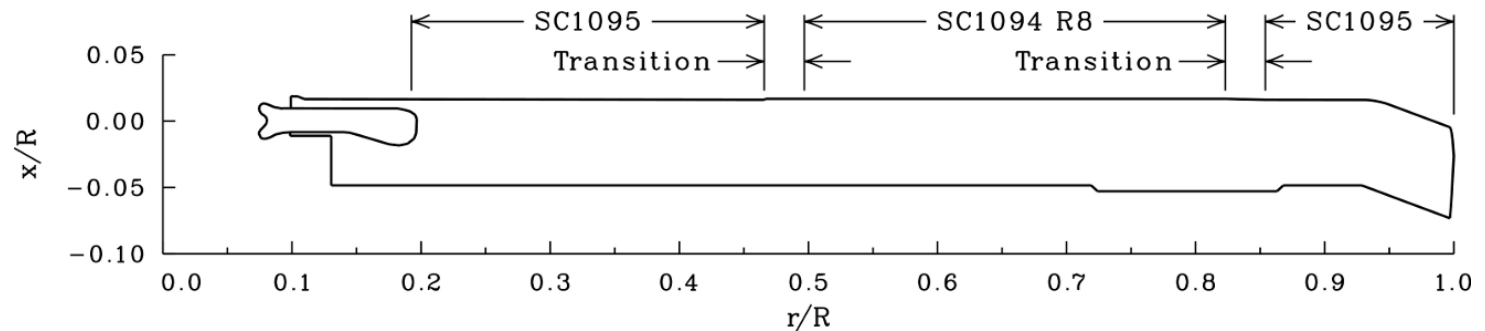
- Test Data
- Coupled Simulation (from CAMRAD II)
- ◆ Coupled Simulation (from OVERFLOW)

Planform Unification

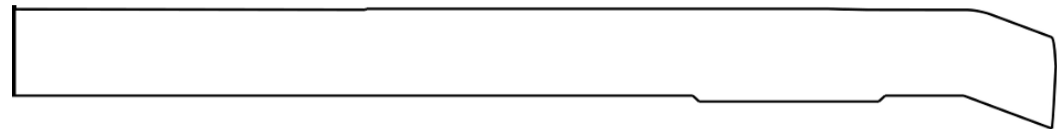


- CAMRAD II model began just outboard of blade grip; CFD grid extends inboard to $r/R=7\%$
- Approx 1% of CFD predicted thrust comes from the region between $r/R=7\%$ and 19%
- Very small adjustments were also made to unify chord and twist distribution.
- Blade grip/shank will likely be necessary for accurate performance prediction at high μ

Design



CAMRAD II



CFD Grid



Airload Transfer Resolution

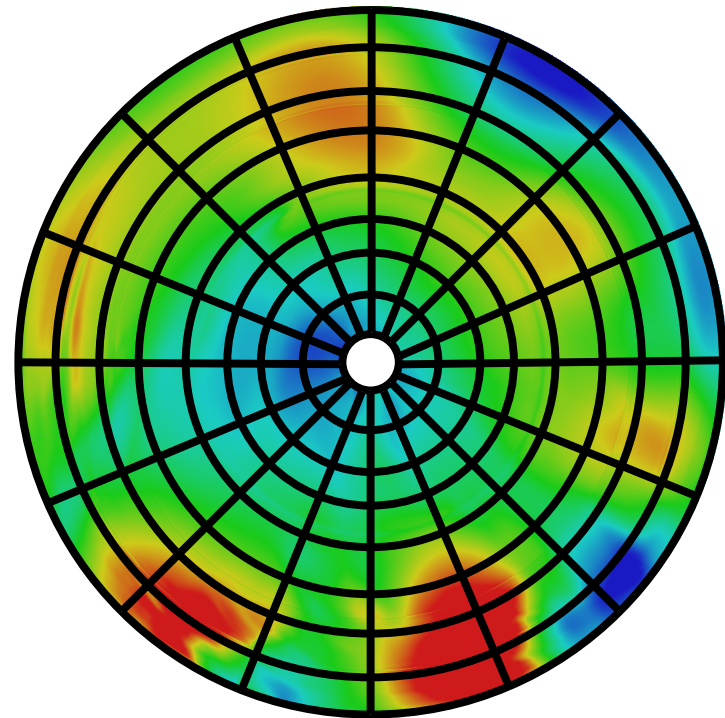


- CFD provides airloads at ~170 radial and 360 azimuthal stations
- Old model downsampled to 21 radial and 24 azimuthal locations
- Define sampling error:

$$\text{exact} = \int \int_{\text{CFD disk}} c_{n,c,m} \, dr \, d\psi$$

$$\text{sampld} = \int \int_{\text{Sampled Disk}} c_{n,c,m} \, dr \, d\psi$$

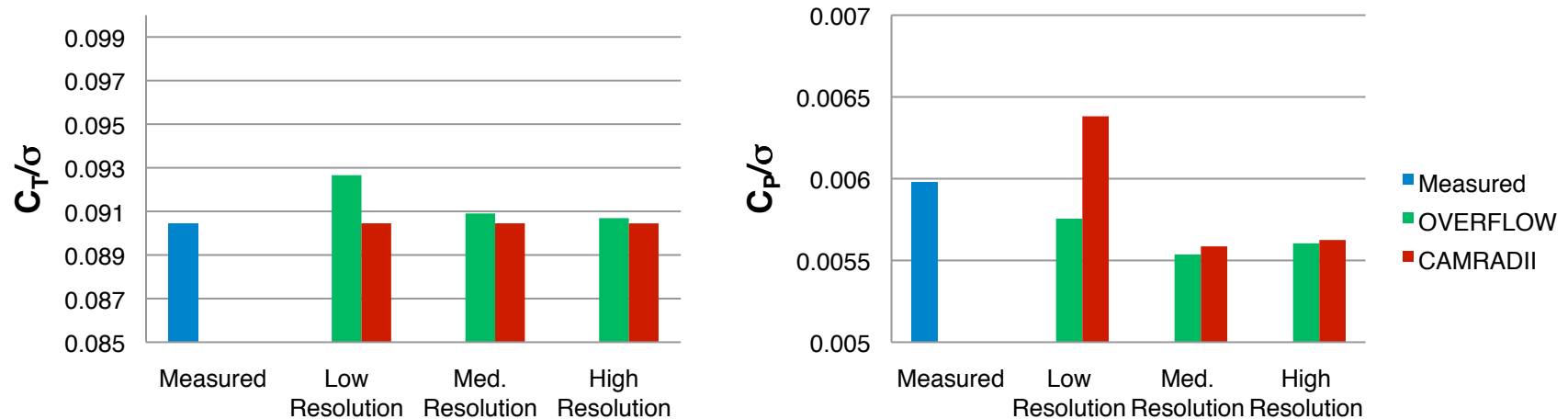
$$\text{error} = \frac{\text{sampld}}{\text{exact}} - 1$$



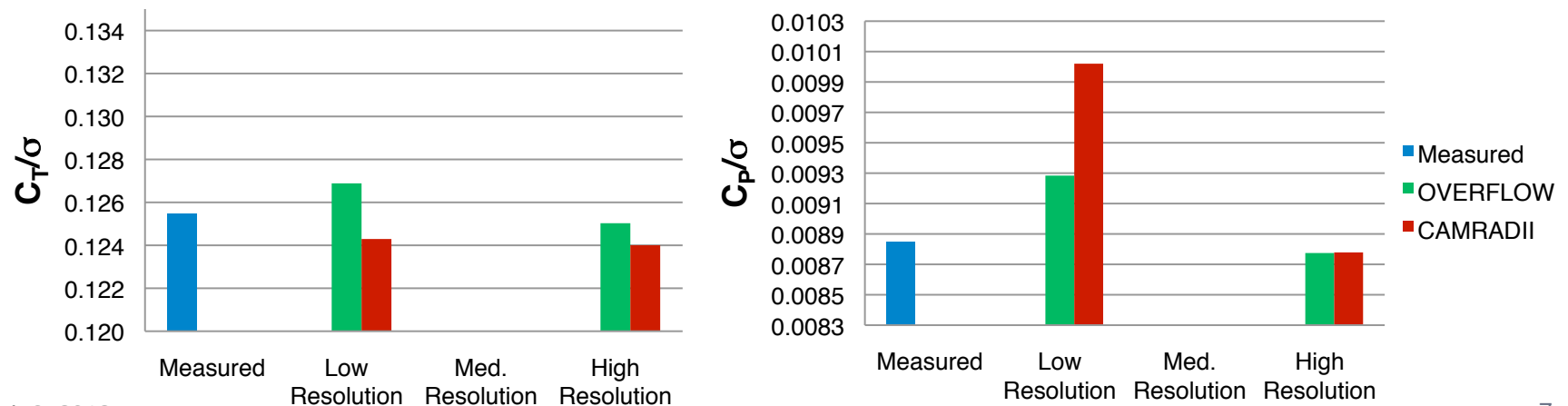
Force Conservation vs. Coupling Resolution



$$C_T/\sigma=0.09, M_{tip}=0.65, \mu=0.3$$



$$C_T/\sigma=0.1255, M_{tip}=0.625, \mu=0.3$$





Measured / Predicted Blade Motion Comparisons

Ethan Romander

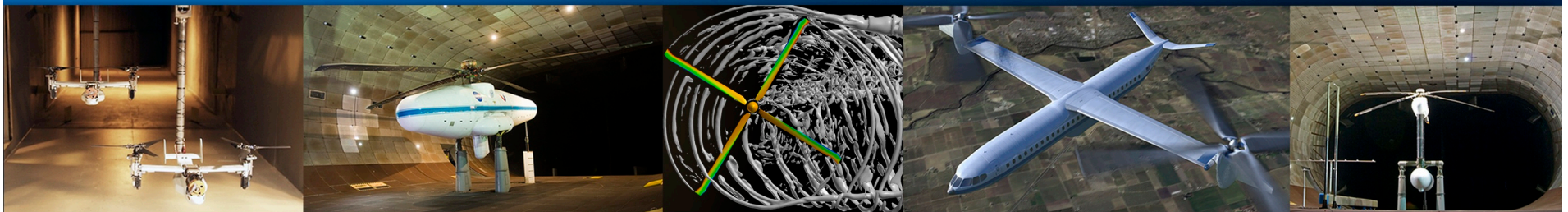
Anita Abrego

Al Burner

Danny Barrows

Larry Olson

UH-60 Airloads Workshop – March 8, 2012



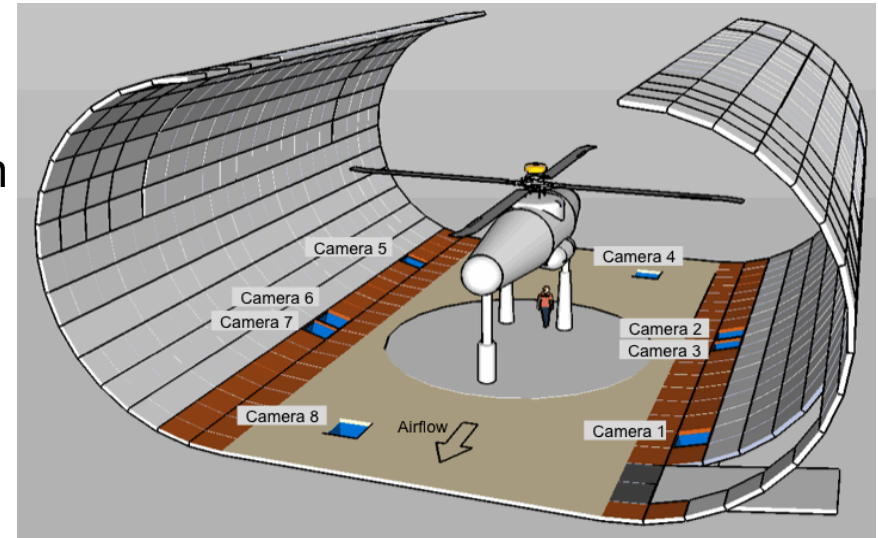
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Blade Displacement Measurements



Setup/Hardware

- 8-cameras, 2 per rotor quadrant
- 4-Mega-pixel, 12-bit CCD progressive scan digital cameras, with a pixel resolution of 2048×2048 pixels
- Nikon 10.5 mm f/2.8 DX (fish-eye) lenses
- Xenon flash-lamp 50 mJ strobes

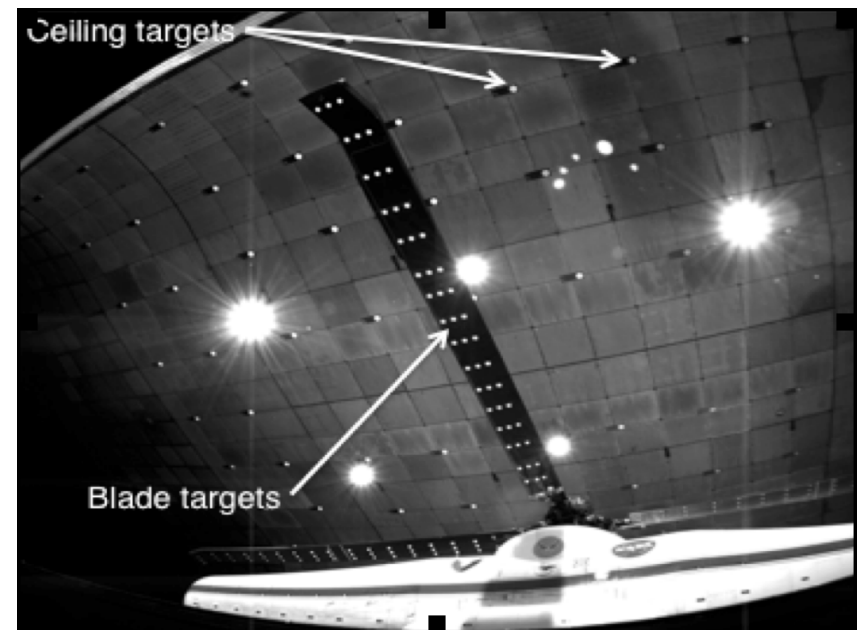


Blades

- Targets on the lower surface of each blade
- 48 retro-reflective targets, 2 inch dia.
- 3 per radial station at r/R from 0.2 to 0.97

Ceiling

- 84 retro-reflective targets, 6 inch dia.
- 84 coded targets

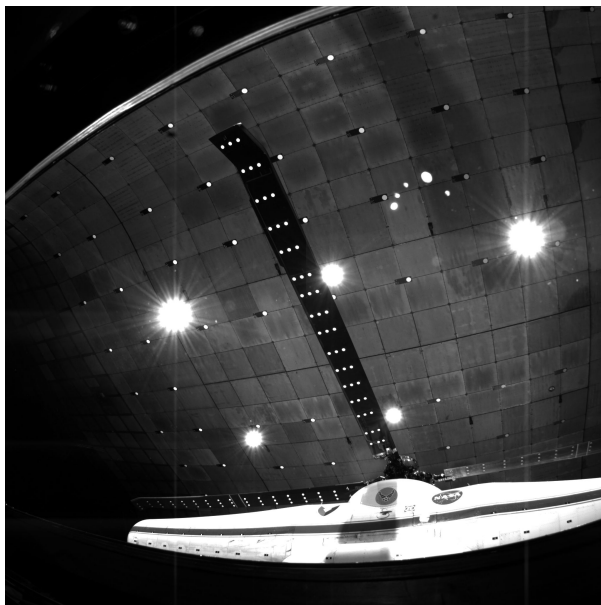


Data Reduction and Validation

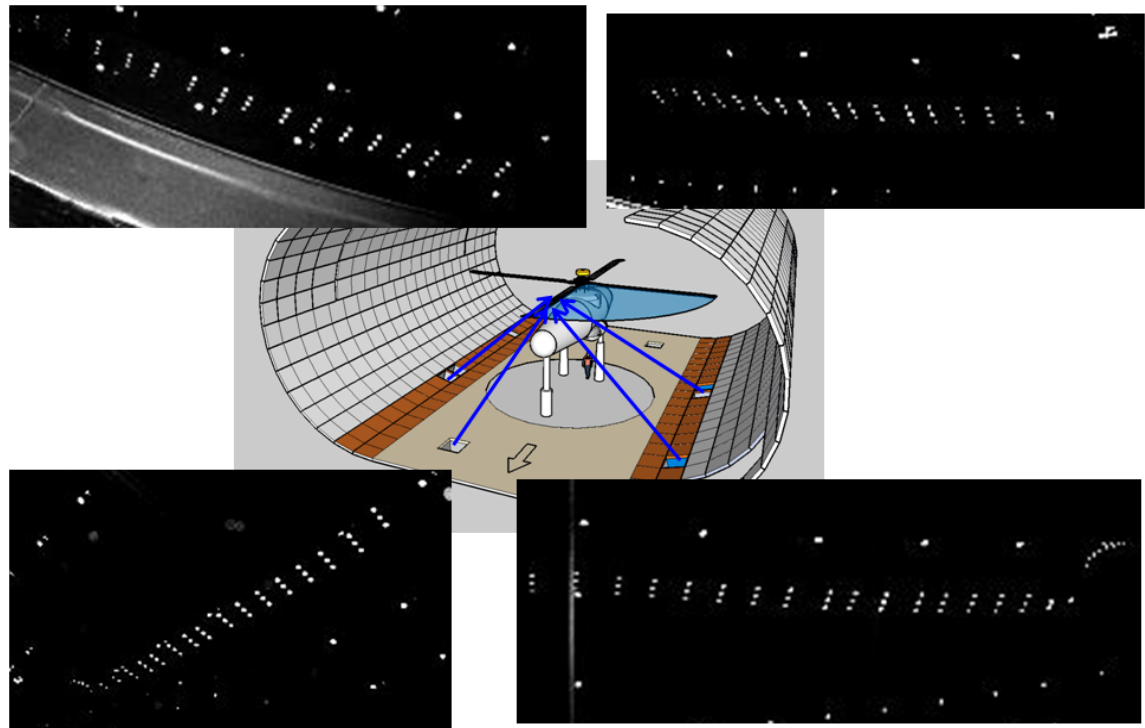


BD 4- camera intersection

Synchronously captured images from 4 different cameras of blade 1



Long-exposure ($\sim 10\text{ms}$)
view of quadrant-1 from
BD data camera 2

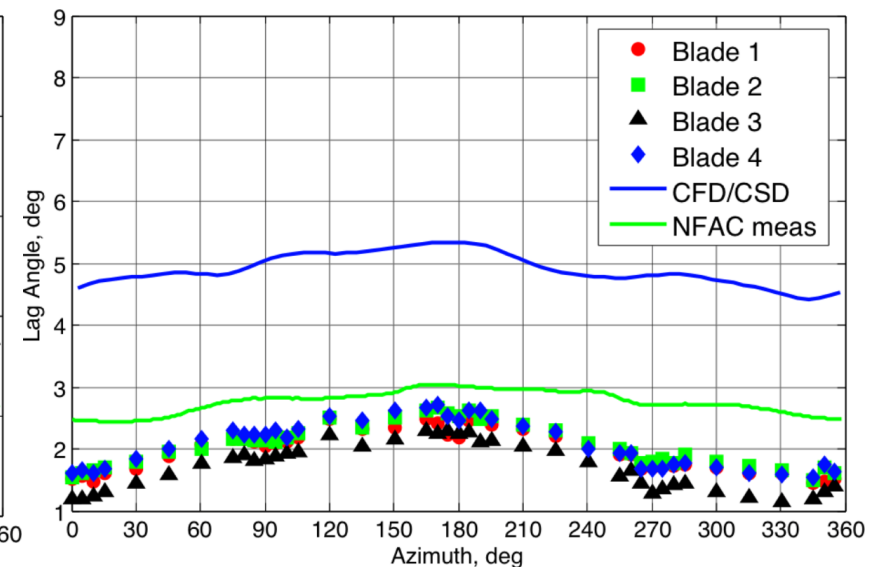
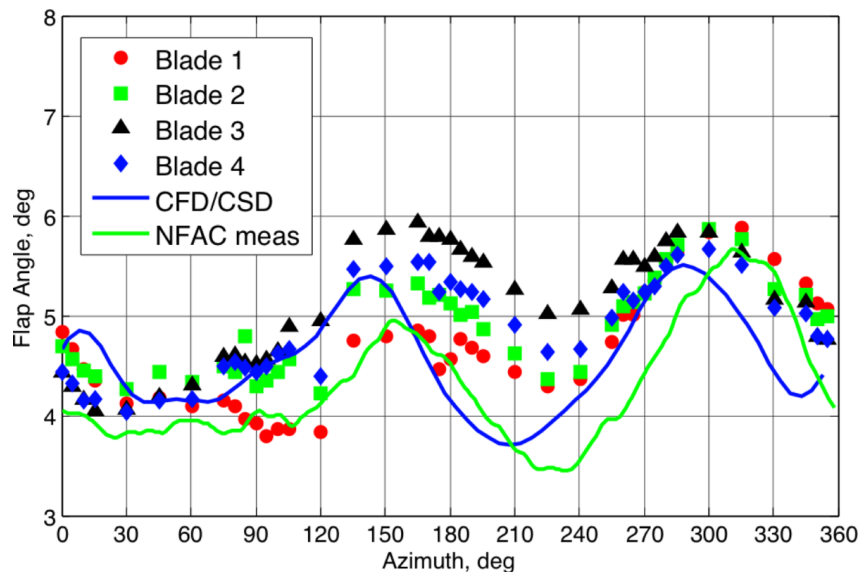
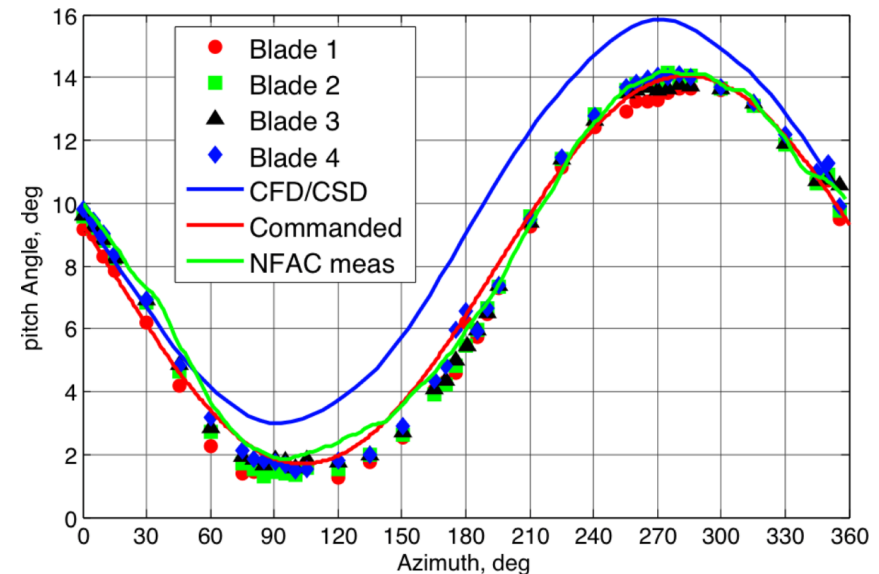


10 $\mu\text{-sec}$ data shot exposures

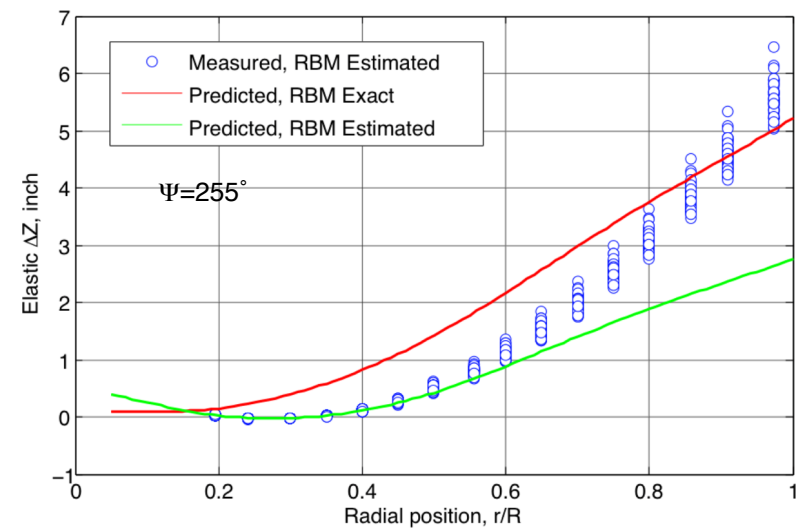
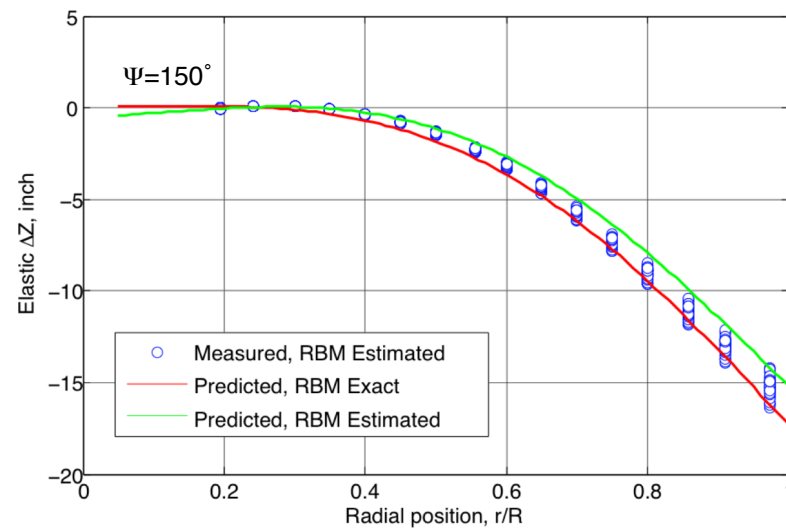
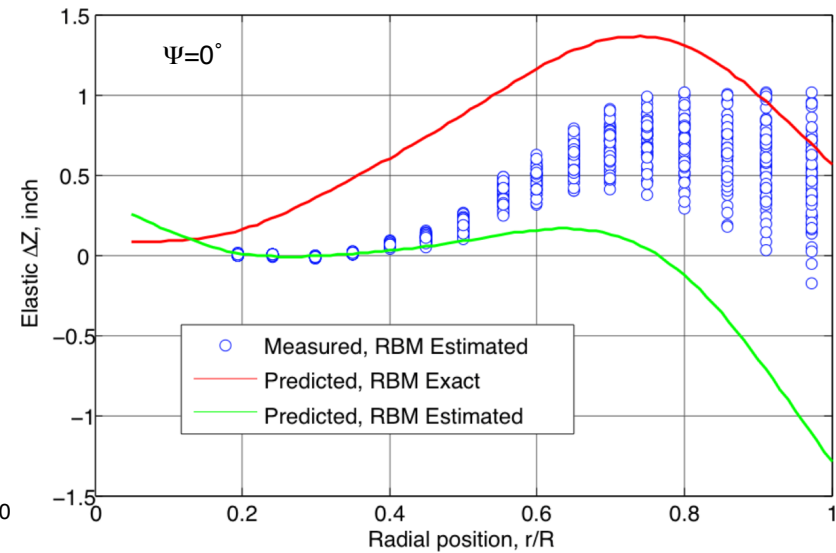
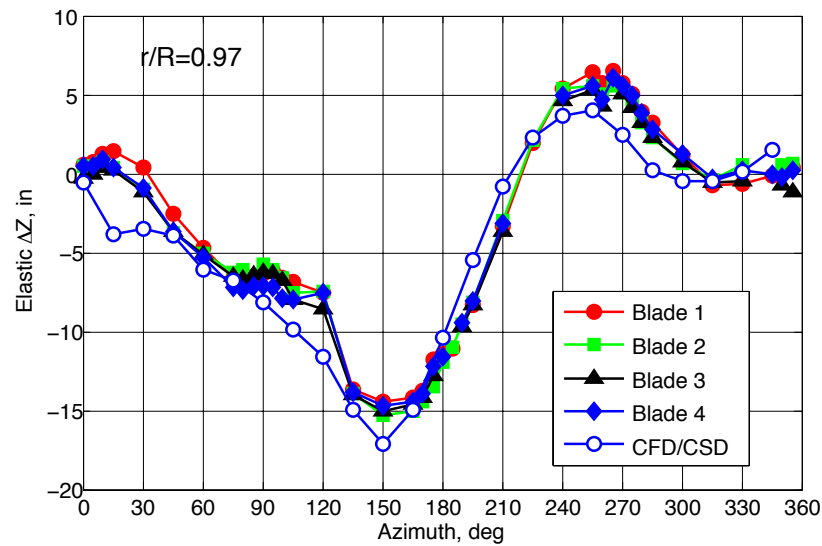
Rigid Body Motions



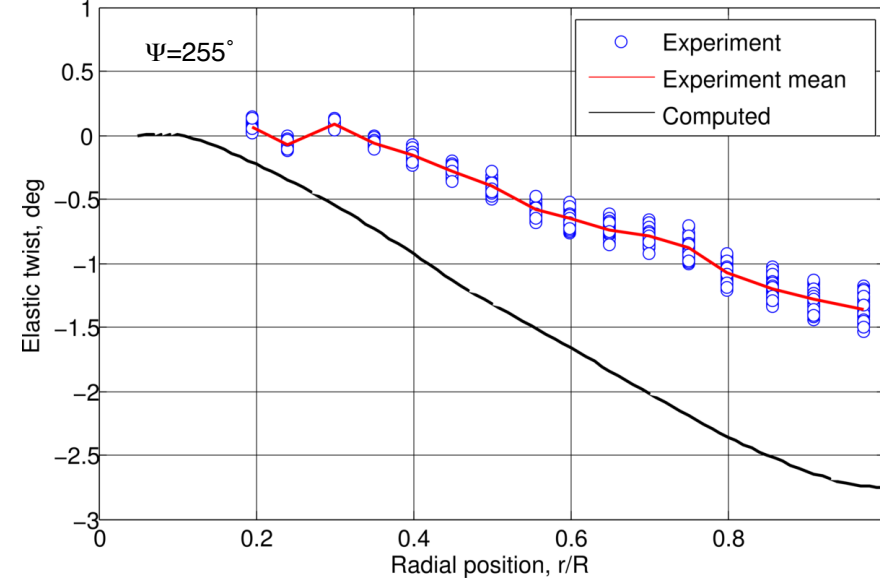
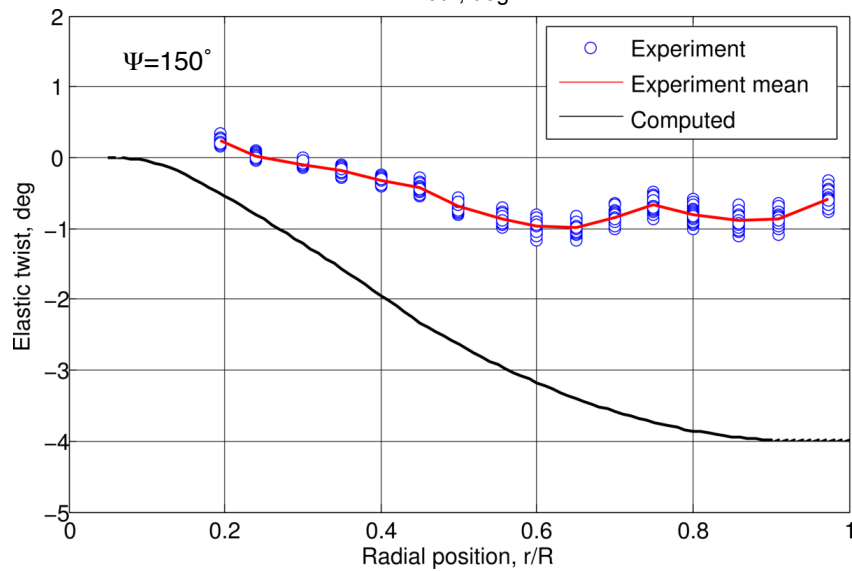
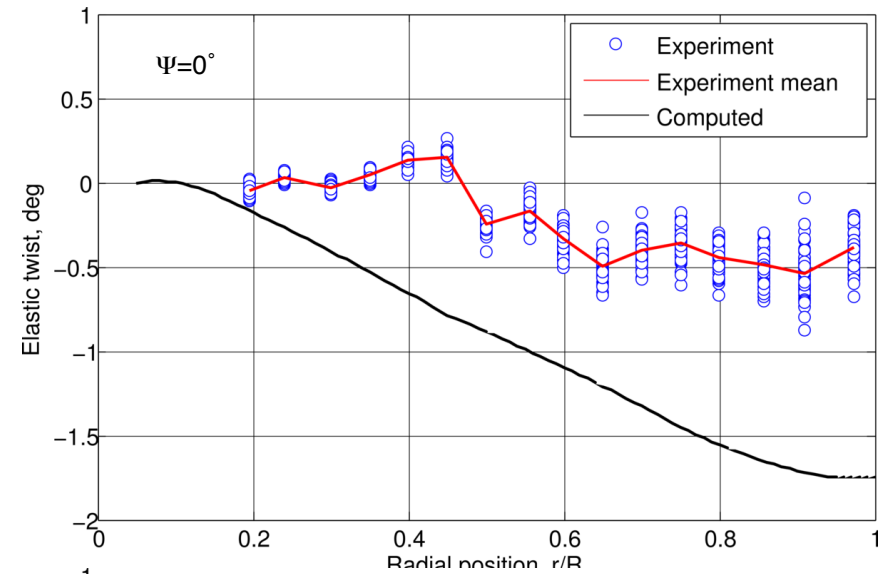
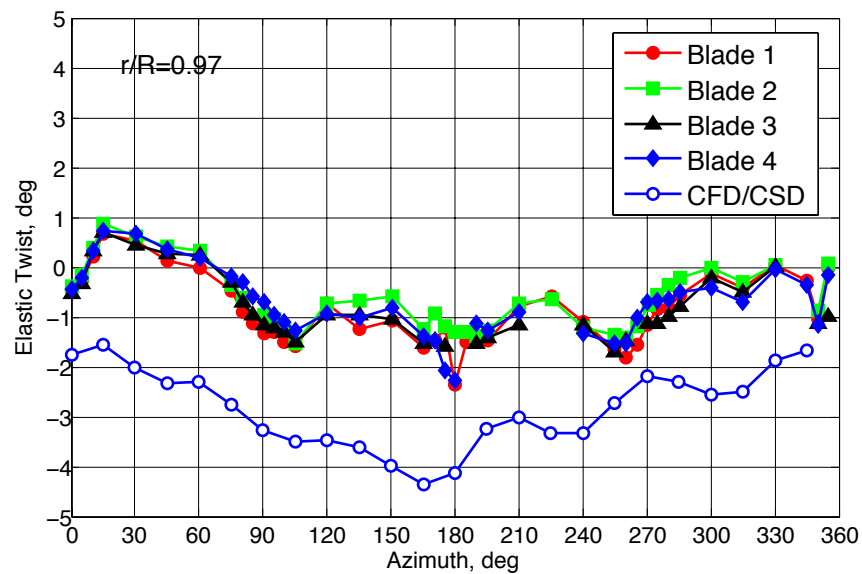
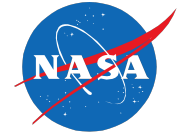
- Run 42, Points 60-63
- $C_T/\sigma=0.10$, $M_{tip}=0.65$, $\mu=0.3$
- Measured Rigid Body Motions (RBM) estimated from targets at $r/R=0.2, 0.25, 0.3, 0.35$.



Out of Plane Bending



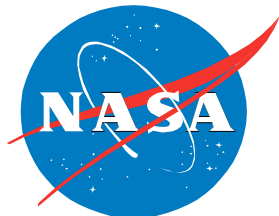
Elastic Twist



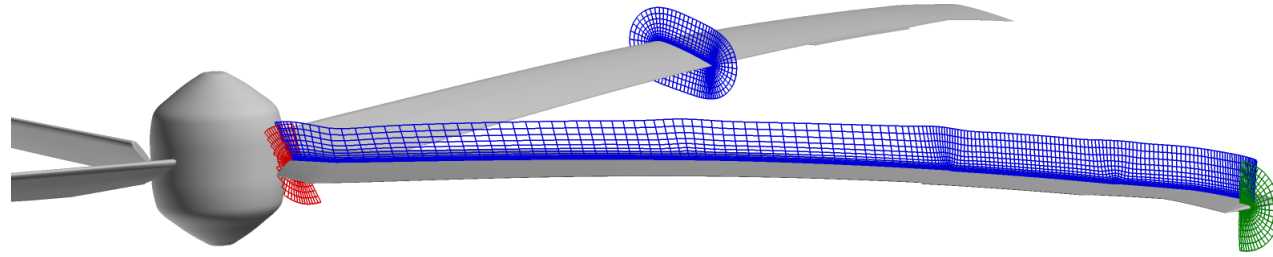
Summary



- Part 1 – Force Conservation
 - Increasing CAMRAD panel count and adding aerodynamic panels to account for inboard portion of rotor cures most of the force conservation issue.
 - Increasing azimuthal resolution improves conservation somewhat but can be a pain to implement.
- Part 2 – Blade Motion Comparisons
 - Preliminary comparisons of RBM look reasonable. Trends are good but there are issues with means (pitch, lag) and phase (flap).
 - Elastic deformation is more difficult to compare primarily due to difficulties in estimating and removing RBM.
 - Abrego, A., et al. “Blade Displacement Measurement Technique Applied to a Full-Scale Rotor Test”. 2012 AHS Forum.



CFD Grid



- As-built blade geometry with notional centerbody
- Blade grid: 157x163 chord/span, O-mesh, $y^+=1$
- Free-air simulation using wall corrected data
 - Tunnel wall model available
- Finest off-body spacing was 10% C_{tip}
- 27M points total (11.5M in near-body)

Modeling Improvements

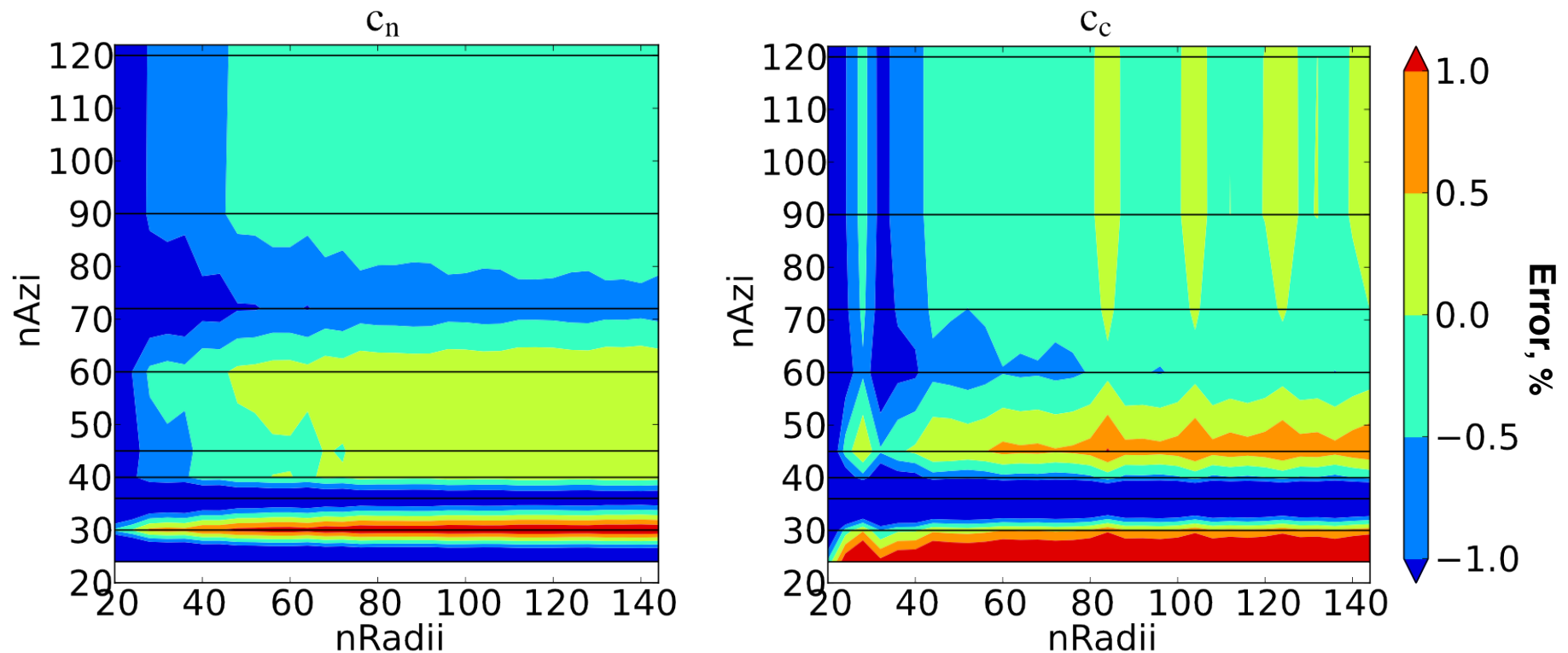


- CAMRAD II / OVERFLOW platform unification
- High resolution airload transfer

Sampling Error: $\mu=0.3$, $C_T/\sigma=0.1255$



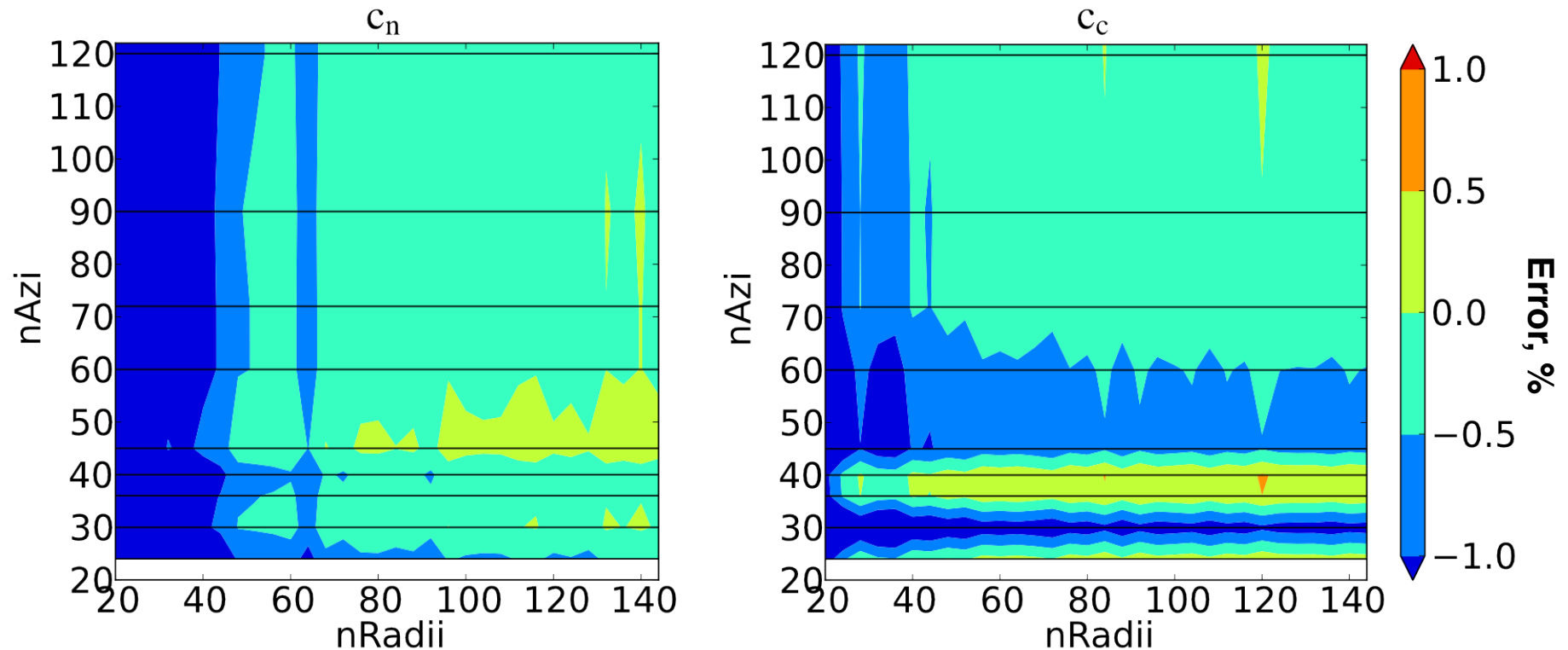
- Deep stall features large azimuthal gradients.
- 80 or more spanwise samples plus >90 timesteps required for optimum force conservation.



Sampling Error: $\mu=0.3$, $C_L/\sigma=0.09$



- Radial gradients dominate at this condition.
- 100 or more spanwise samples required for optimum force conservation.



Force Prediction with New Model

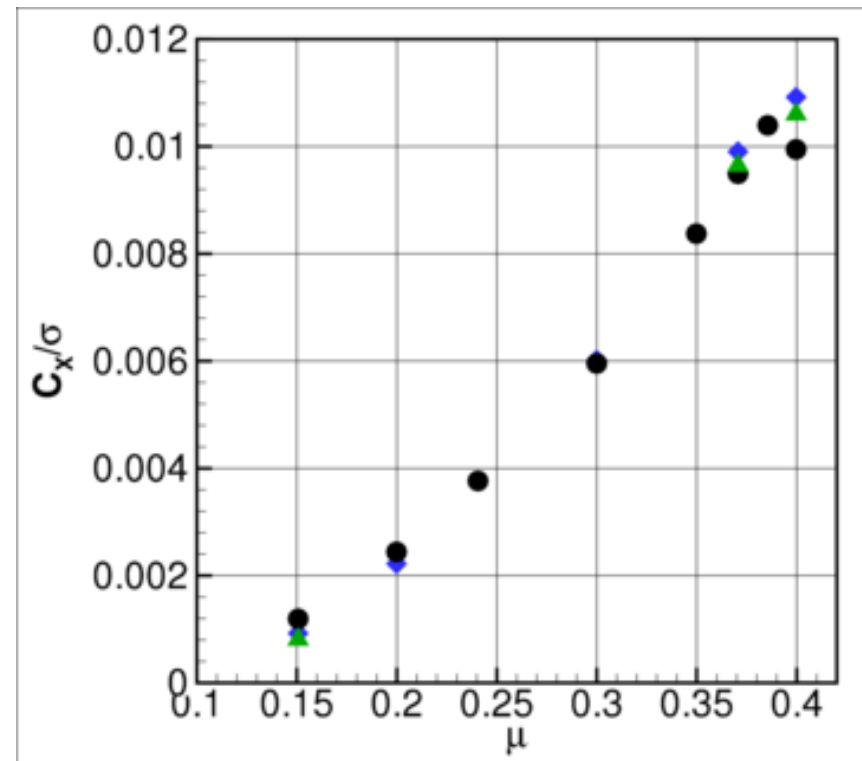
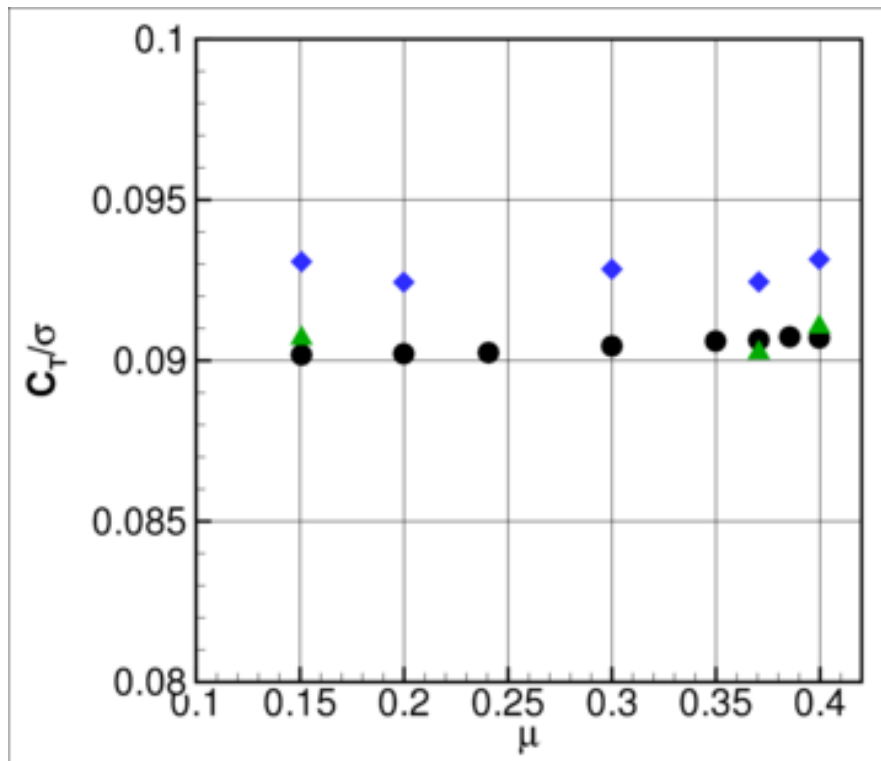


- CAMRAD II and OVERFLOW agree on F&M well within 1%
- Propulsive force decreased across speed range

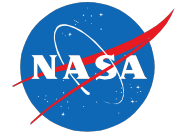
● Test

◆ Old CAMRAD Model

▲ Improved CAMRAD Model



Power Prediction with New Model

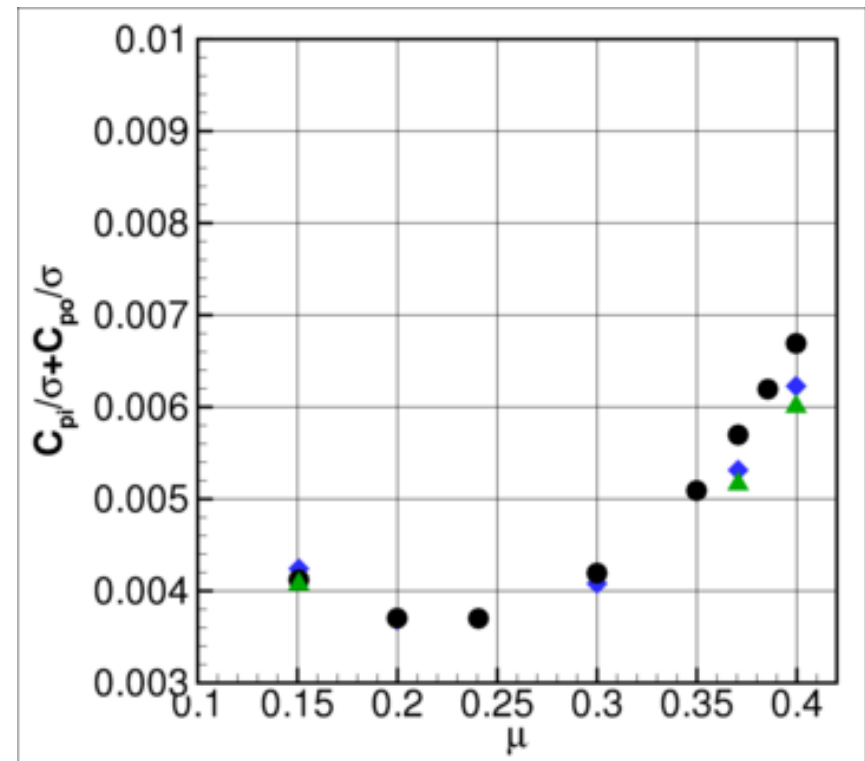
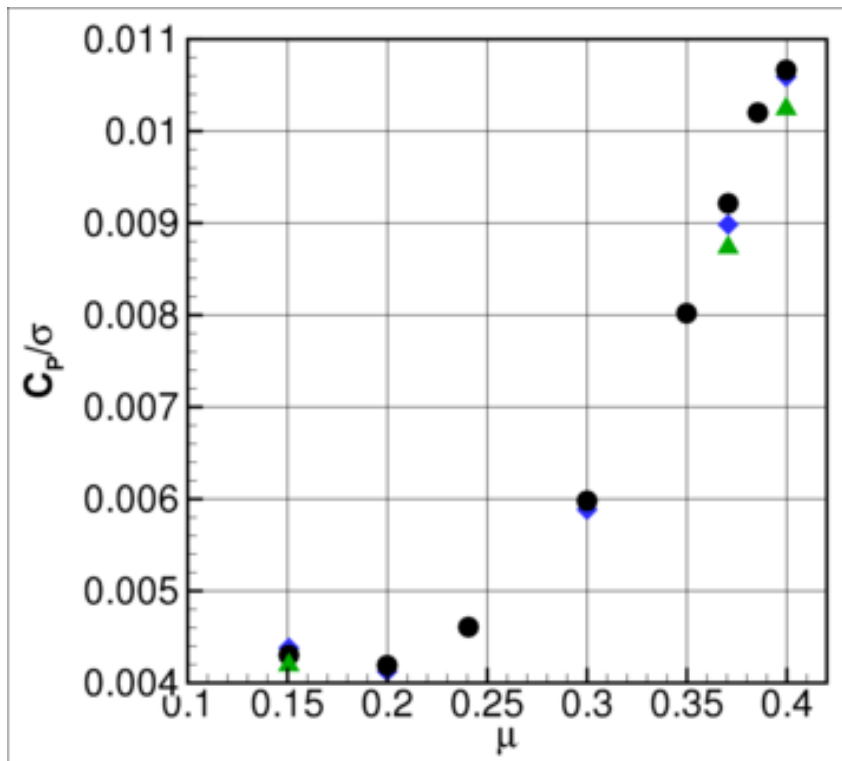


- Total power is reduced across speed range for new model
- Induced and profile power continue as the dominant sources of error

● **Test**

◆ **Old Model**

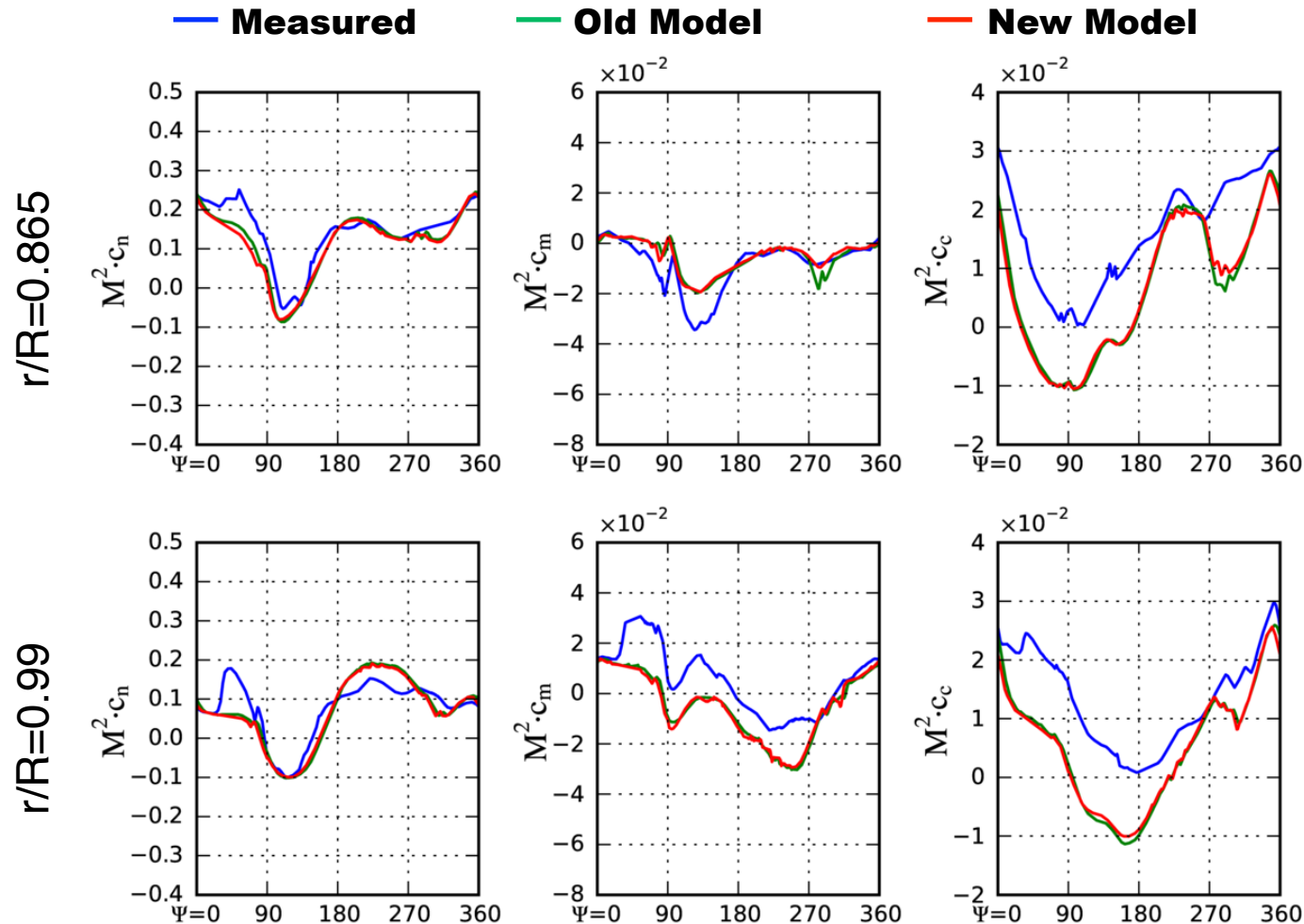
▲ **Improved Model**



Airload Comparison: $\mu=0.4$, $C_L/\sigma=0.09$



- Airload changes are small and consistent with reduced thrust.

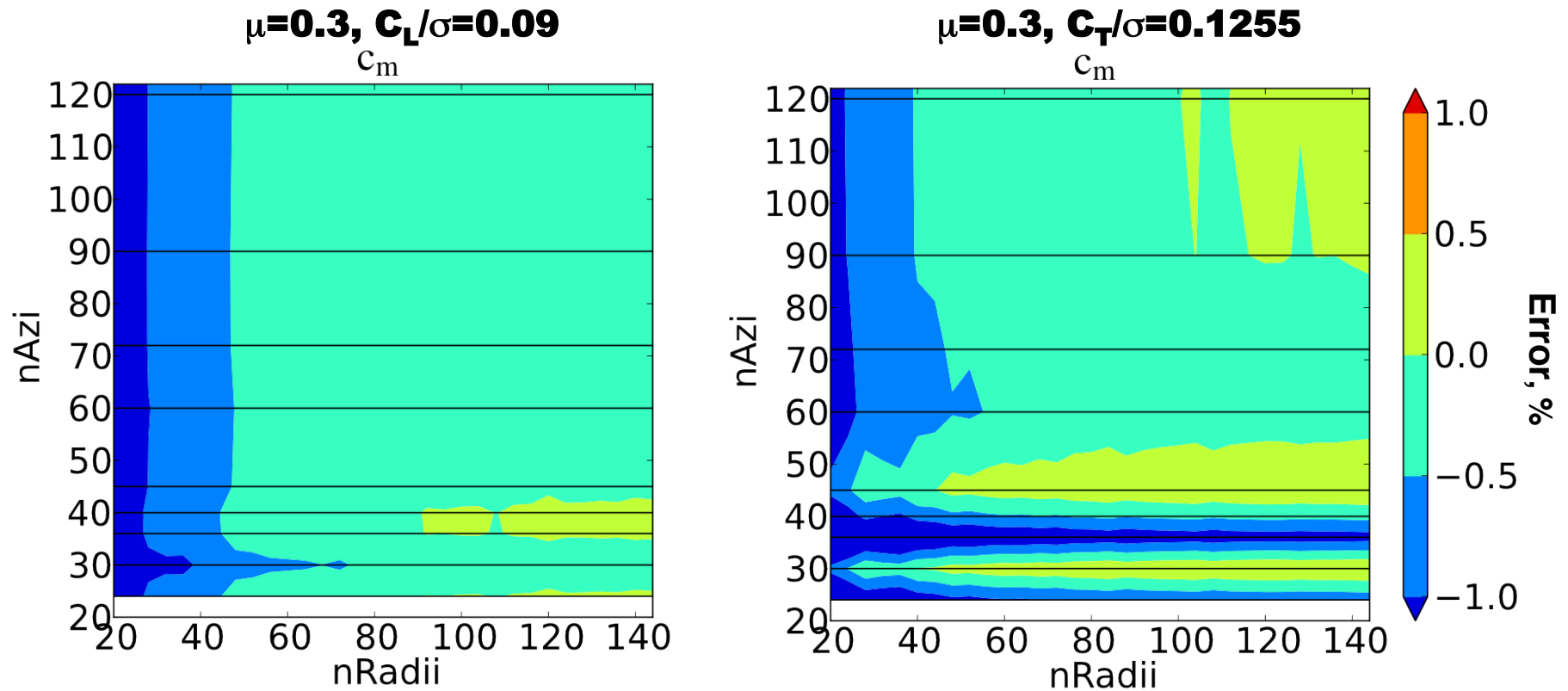


Summary

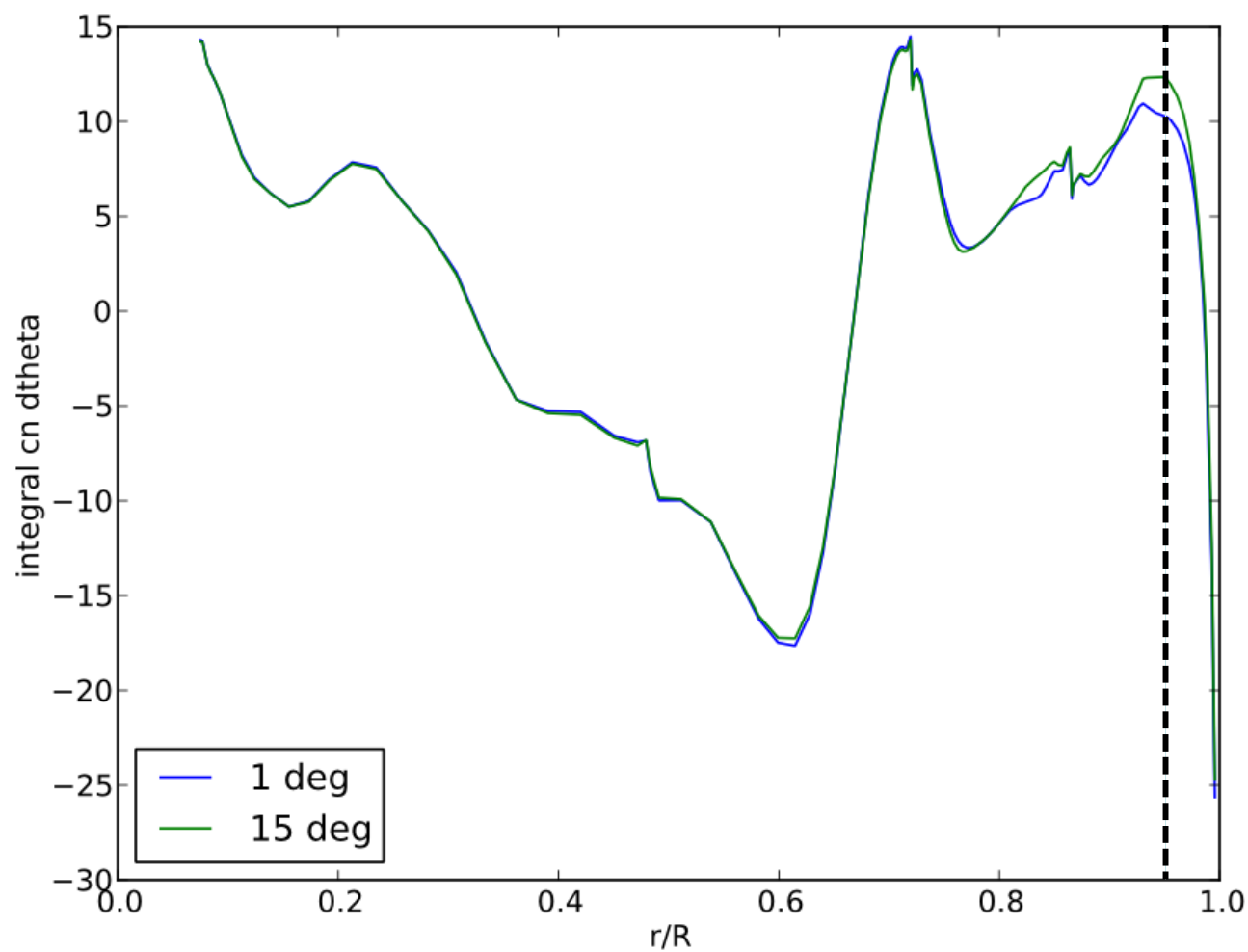


- Force conservation necessitates very careful coordination between CFD grid and CSD representation
- Downsampling airloads between CFD and CSD introduces significant error:
 - Benign conditions can tolerate large timesteps but still require sufficient spanwise resolution
 - Cases with large azimuthal gradients (BVI, Stall) necessitate small timesteps in addition to sufficient spanwise resolution
- The improved model cures trim error for the studied speed sweep
- Performance and airloads predictions demonstrate the expected response to improved trim

Moment Coefficient Sampling Error



$\mu=0.3$, $C_T/\sigma=0.1255$



$\mu=0.3$, $C_T/\sigma=0.1255$

